Fully Implicit Hurricane Modeling

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What's new about the model:

1) A physics-based preconditioner has been developed that enables the large 3-D system to be computed in a reasonable amount of time
2) Higher-order in time solution procedures have been utilized (e.g., semi-implicit Runge-Kutta)
3) Implicit AMR is being implemented into the model

Motivation

Over the last 25+ yr there has been little, if any, progress at improving the accuracy of hurricane intensity forecasts (e.g., Elsberry 1997; Emanuel 1998; Marks and Shay).

■AS ALWAYS WITH INTENSITY FORECASTS...I AM FULLY PREPARED TO BE WRONG IN EITHER DIRECTION.

FORECASTER LAWRENCE

FORECAST POSITIONS AND MAX WINDS

INITIAL	30/0300Z	19.2N	78.5W	55 KTS
12HR VT	30/1200Z	19.9N	79.6W	60 KTS
24HR VT	01/0000Z	21.2N	81.6W	65 KTS
36HR VT	01/1200Z	22.4N	84.0W	70 KTS
48HR VT	02/0000Z	23.9N	86.3W	80 KTS
72HR VT	03/0000Z	27.0N	90.0W	90 KTS

46A 26.60 -90.30 10/03/00Z 125 940 HURRICANE-4

Model Equation Set + Solution Proceedure

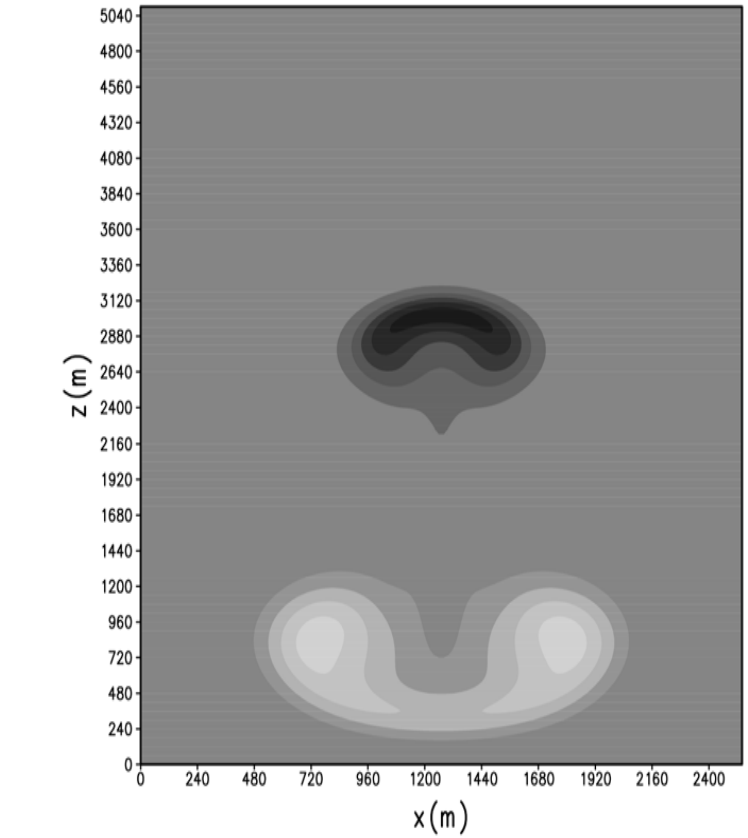
- The chosen equation set is Navier-Stokes plus additional equations to represent precipitation processes (e.g., condensation and falling).
- The equation set is solved via the Jacobian Free Newton-Krylov approach.
- A time-split algorithm capable of solving the Navier-Stokes equation set is used to precondition the fully implicit equation set.
- A parabolic equation is solved in the preconditioner.

Accuracy and Efficiency of the Model

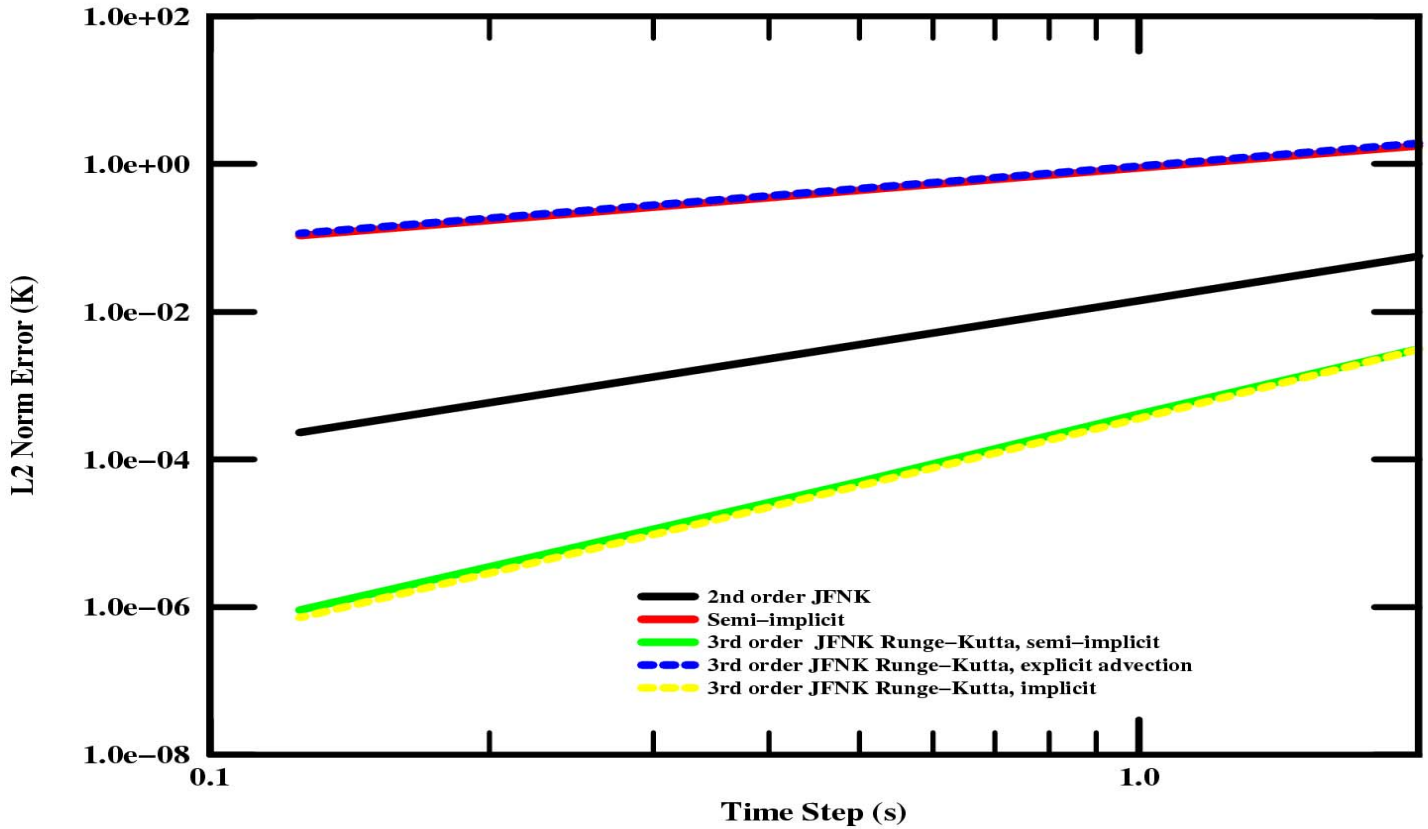
- A 2-D form of the hurricane equation set has been used to determine the accuracy and efficiency of the target equation set.

- The 2-D equation set has been used in the simulation of moist and dry thermals (Reisner et al., 2003, JCP).

2-D Moist Precipitating Bubble



L2 Norm Versus Time Step Size For Moist Bubble



Navier-Stokes without Forcing (Con't)

Physics-Based Preconditioner reduces Krylov Iterations and Timings by a Factor of 10

Type	# of SSOR Cycles	Newt./dt	GMRES/ Newt.	Time(s)	Size
Precon=0		1.97	160.	4550.	64x64
Precon=0		1.98	170.	46283. (10.17)	128x128
Multigrid	2	1.93	15.83	475.	64x64
Multigrid	2	1.98	16.00	4756. (10.01)	128x128
Multigrid	2	2.00	15.45	52526. (11.04)	256x256

Note, this is for a 2nd order method, for a 3rd order method the factor is at least a factor of 100

Do the results from the 2-D Simulations Hold for the Hurricane?

Do time-split algorithms need to run at a time step that resolves that fastest wave in order to produce an accurate hurricane intensity forecast?

Will the physics-based preconditioner be able to reduce the number of Krylov iterations such that the algorithm is able to run efficiently in 3-D?

Hurricane Opal

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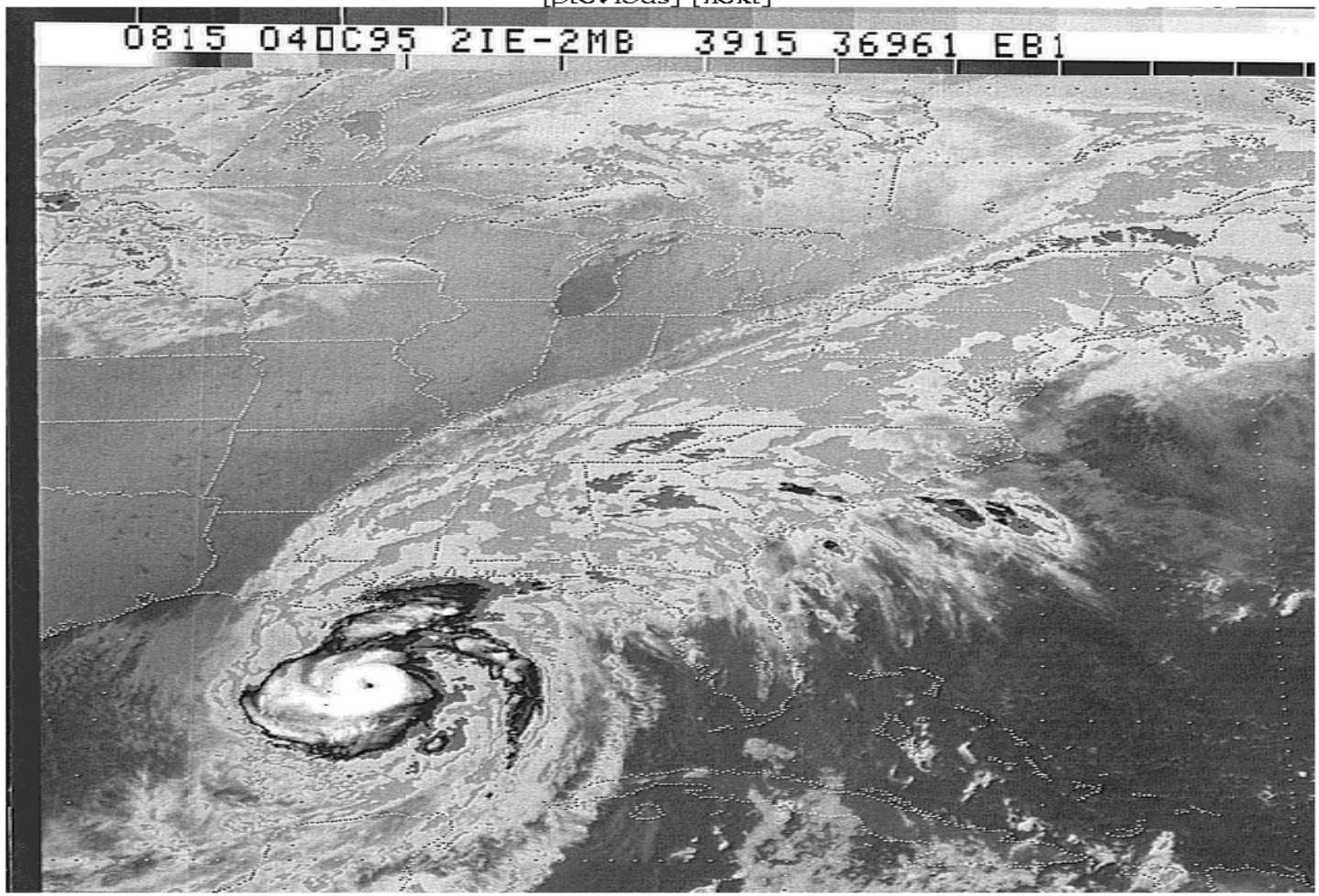

Fig. 11. Infrared (IR) *GOES-8* satellite image for 0815 UTC 4 Oct 1995, operational MB curve enhancement.

Bosart et al. 2000, MWR, 128, 322-252

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Track of Hurricane Opal and Location of Warm-Core Eddy (WCE)

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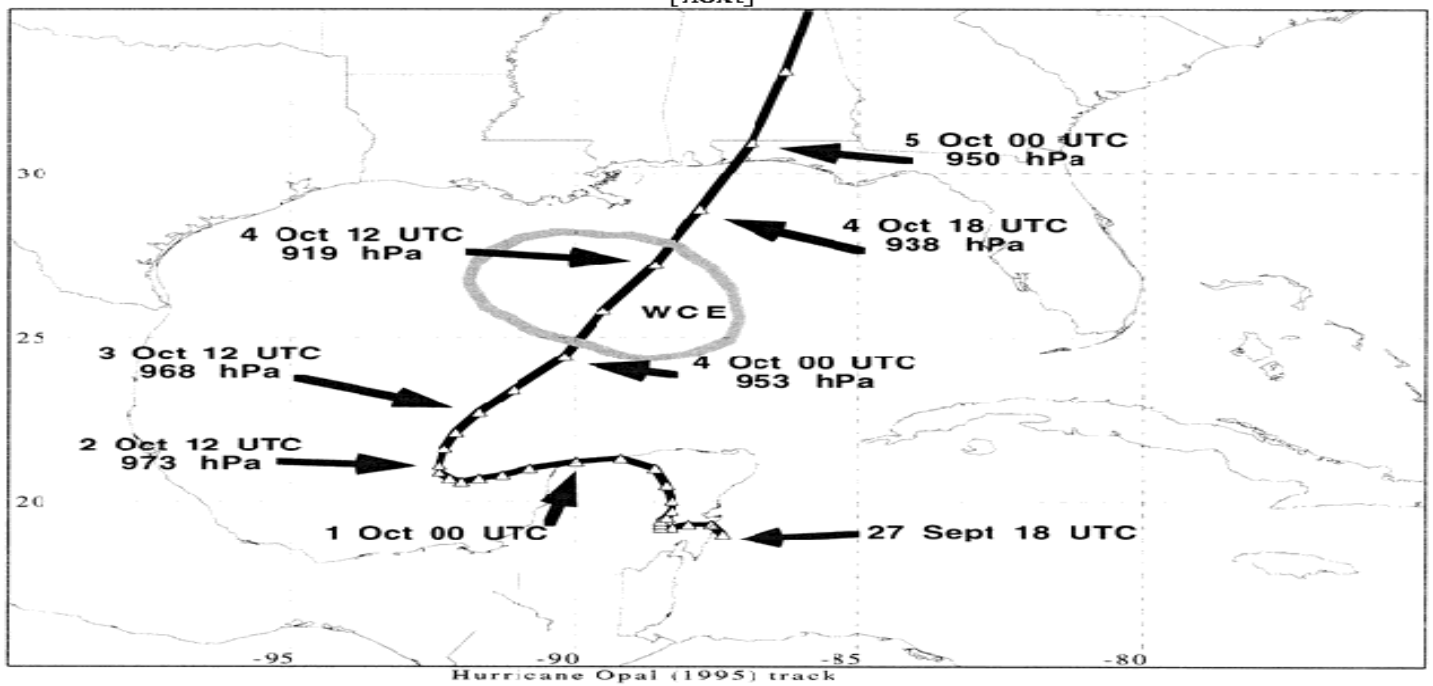

Fig. 1. Track of Hurricane Opal over the period 27 Sep-5 Oct 1995. Storm position indicated every 6 h by the open triangles. Storm central pressure (hPa) is indicated at selected time periods. Warm-core eddy (WCE) outlined in gray.

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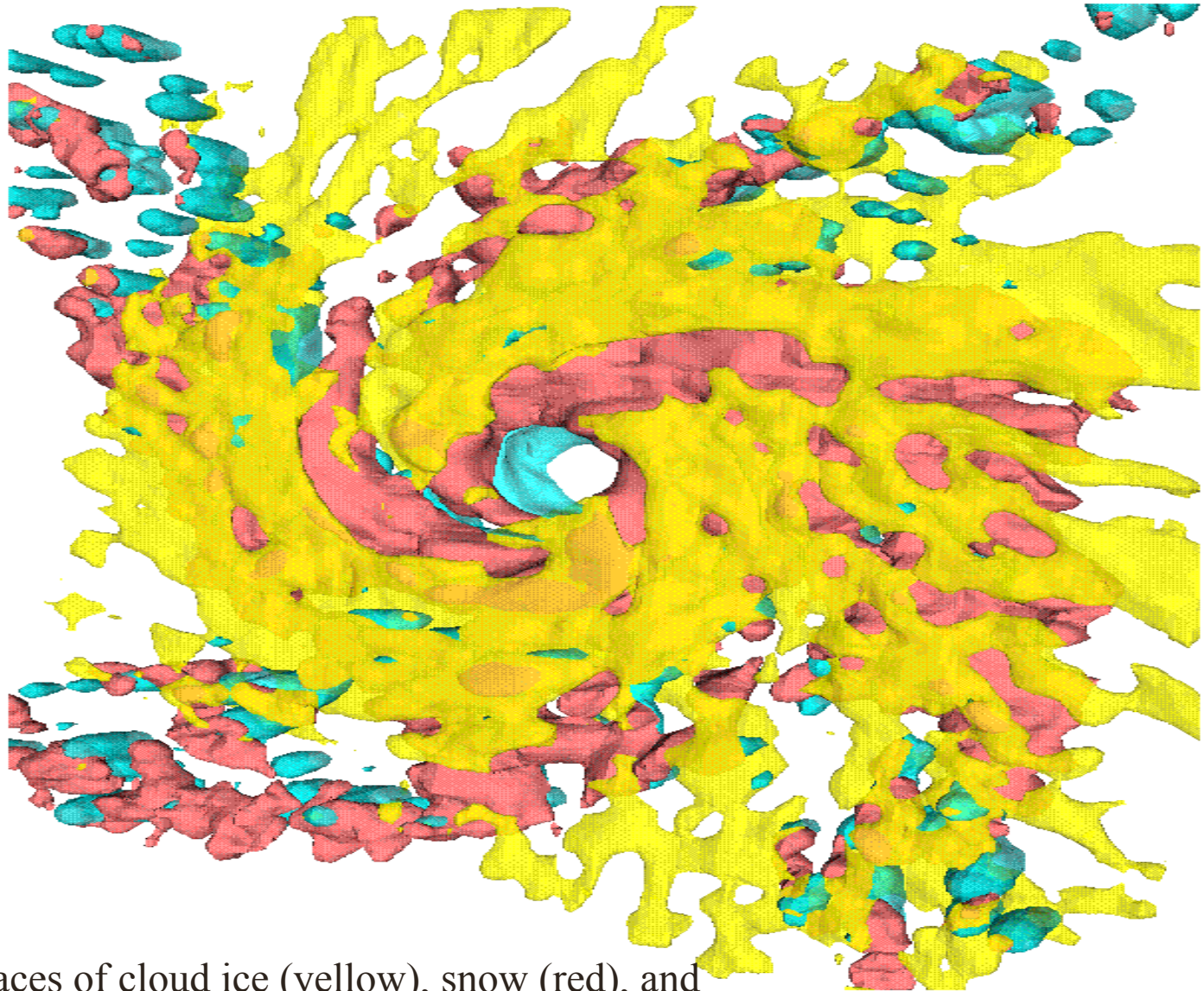
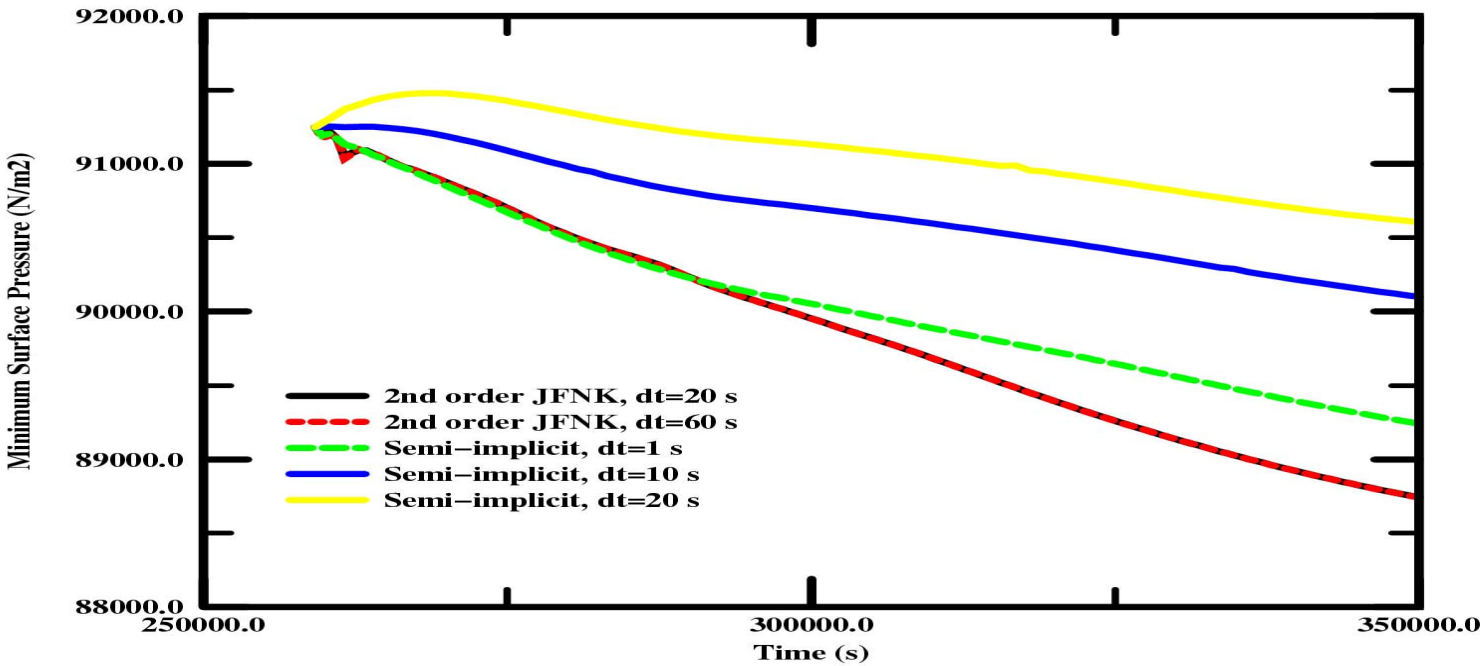
Hurricane Model Settup

- Idealized hurricane simulations employing 150x150x51 grid points with 10 km horizontal resolution and 300 m vertical resolution have been run.
- An idealized hurricane simulation was run until an approximate steady-state solution was reached. This involved about 3.0 days of actual time and about 2 days of computer time on 25 alpha processors.
- Next various idealized hurricane simulations utilizing different numerical approaches and time step sizes were run for a warmer sea-surface temperature using the above steady-state solution as an initial guess.

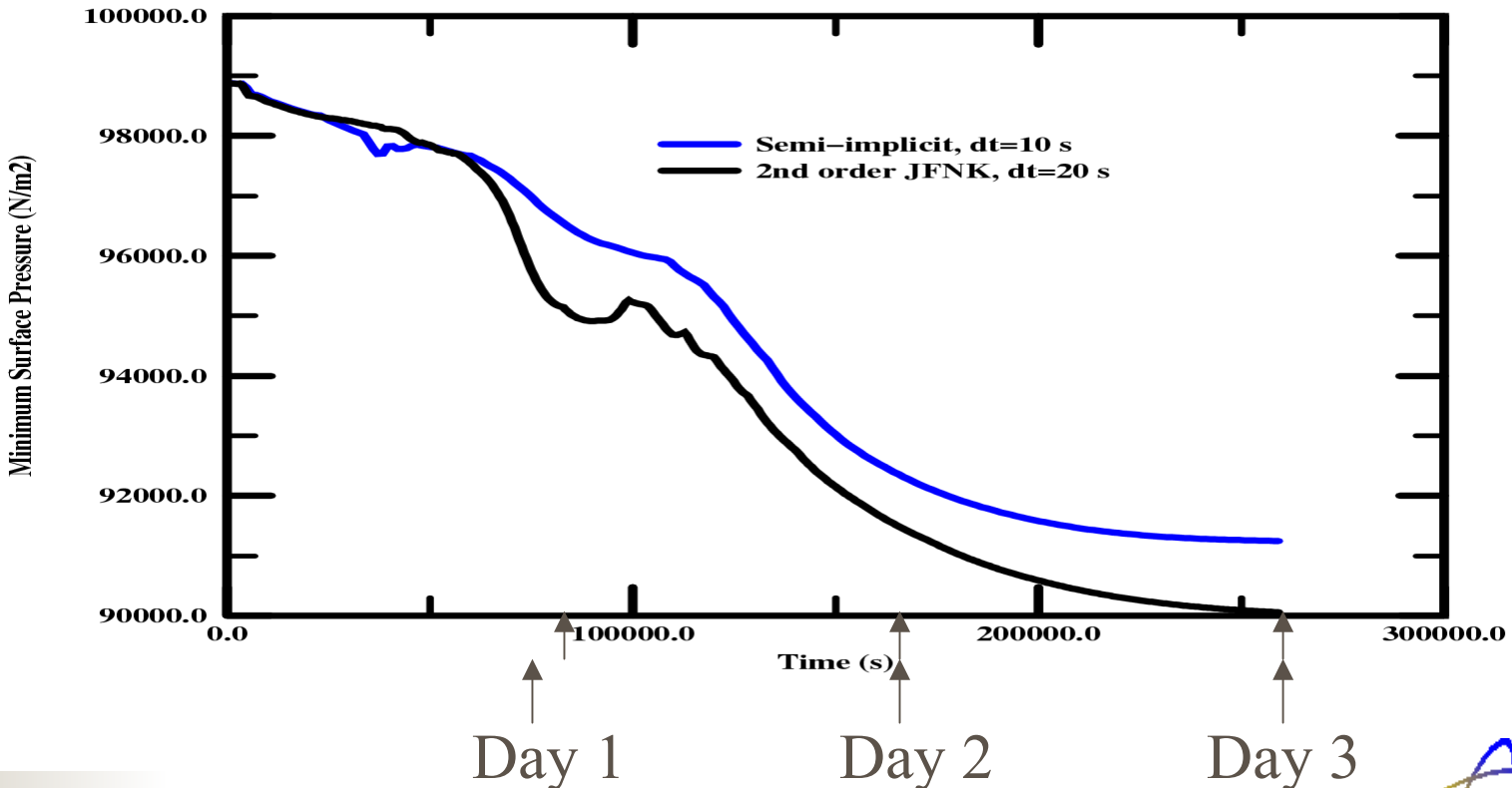


Isosurfaces of cloud ice (yellow), snow (red), and rain water (blue) from a simulated hurricane

Hurricane Results (con't)
Minimum Surface Pressure Versus Time From JFNK or Split Solvers



Minimum Surface Pressure Versus Time



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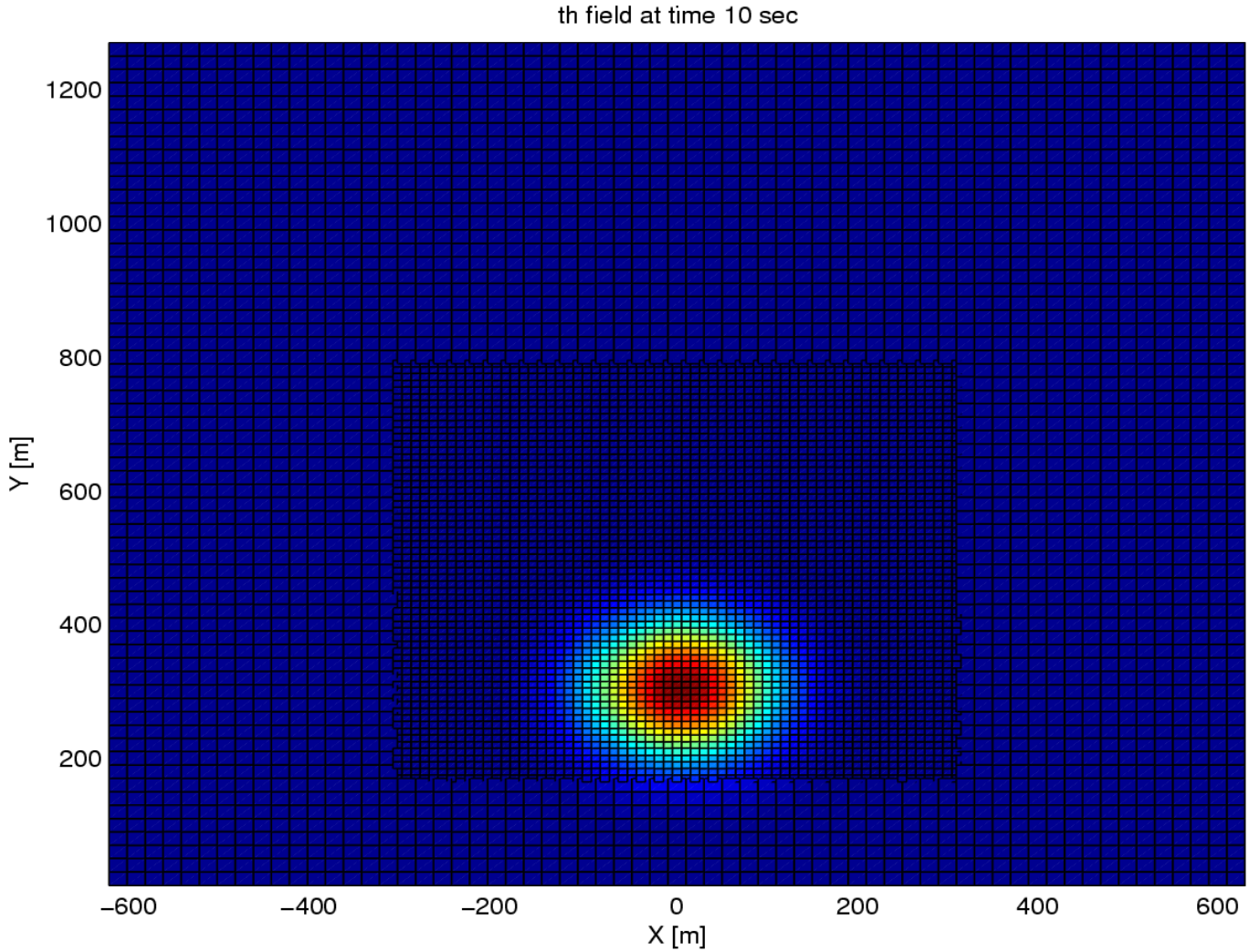
Efficiency of Preconditioner Used in Hurricane Simulations

Δt	GMRES-PRE	Time-Pre	GMRES-NoPre	Time-NoPre
5	13	41	43	89
10	14	42	72	125
20	14	43	102	155
40	17	44	378	590
60	22	46	519	780
90	60	63	728	1400
120	75	85	910	

Implicit AMR:
We need any helpful suggestions?

- Over the past year have "rewritten" a parallel AMR solver developed at NASA, PARAMESH, to allow for implicit AMR
- Target problem is currently a dry 2-D bubble incorporating a relatively complex two TKE level turbulence model
- Able to achieve higher-order accuracy in time for a static mesh, moving mesh is more difficult…

Static Mesh, Potential Temperature



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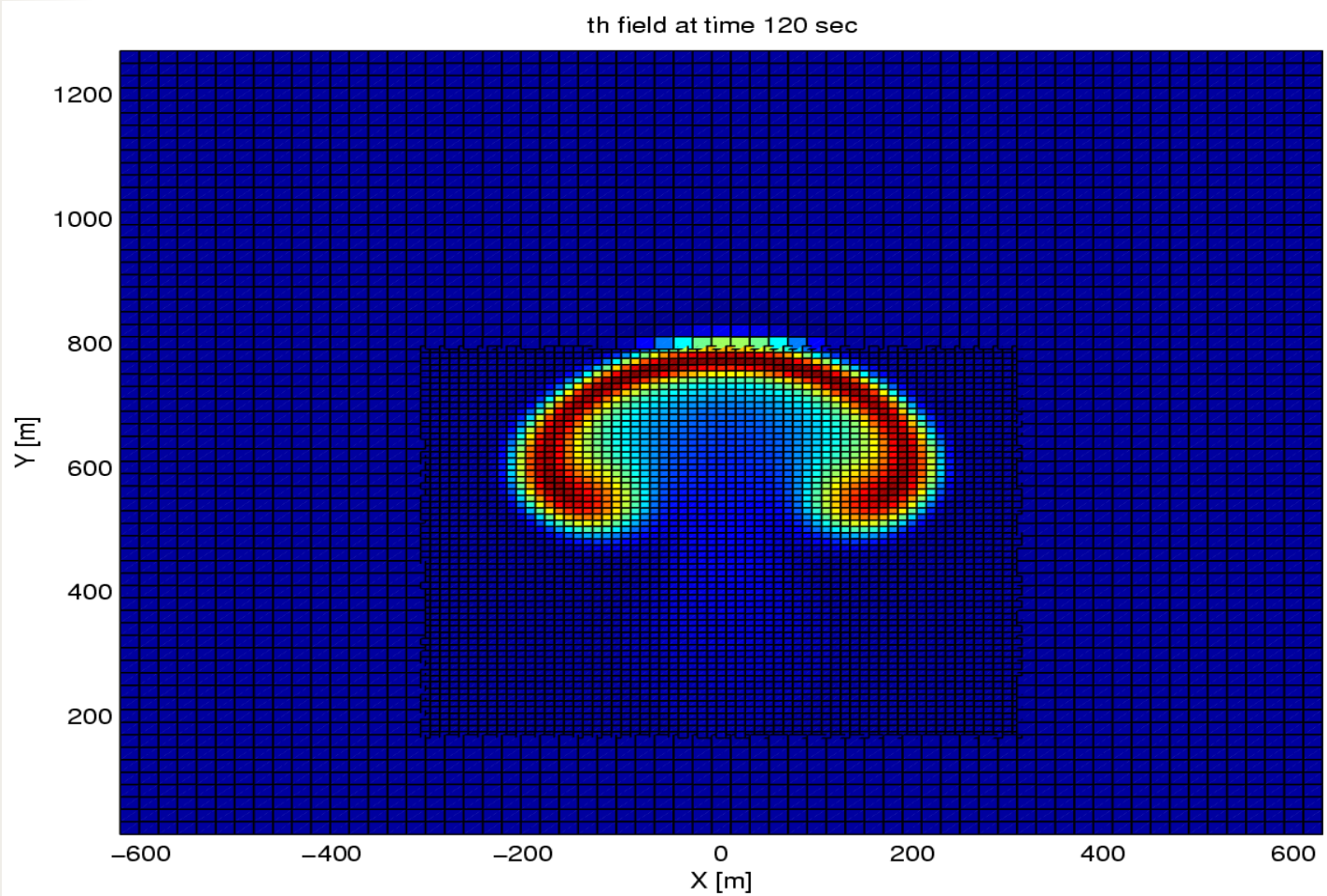

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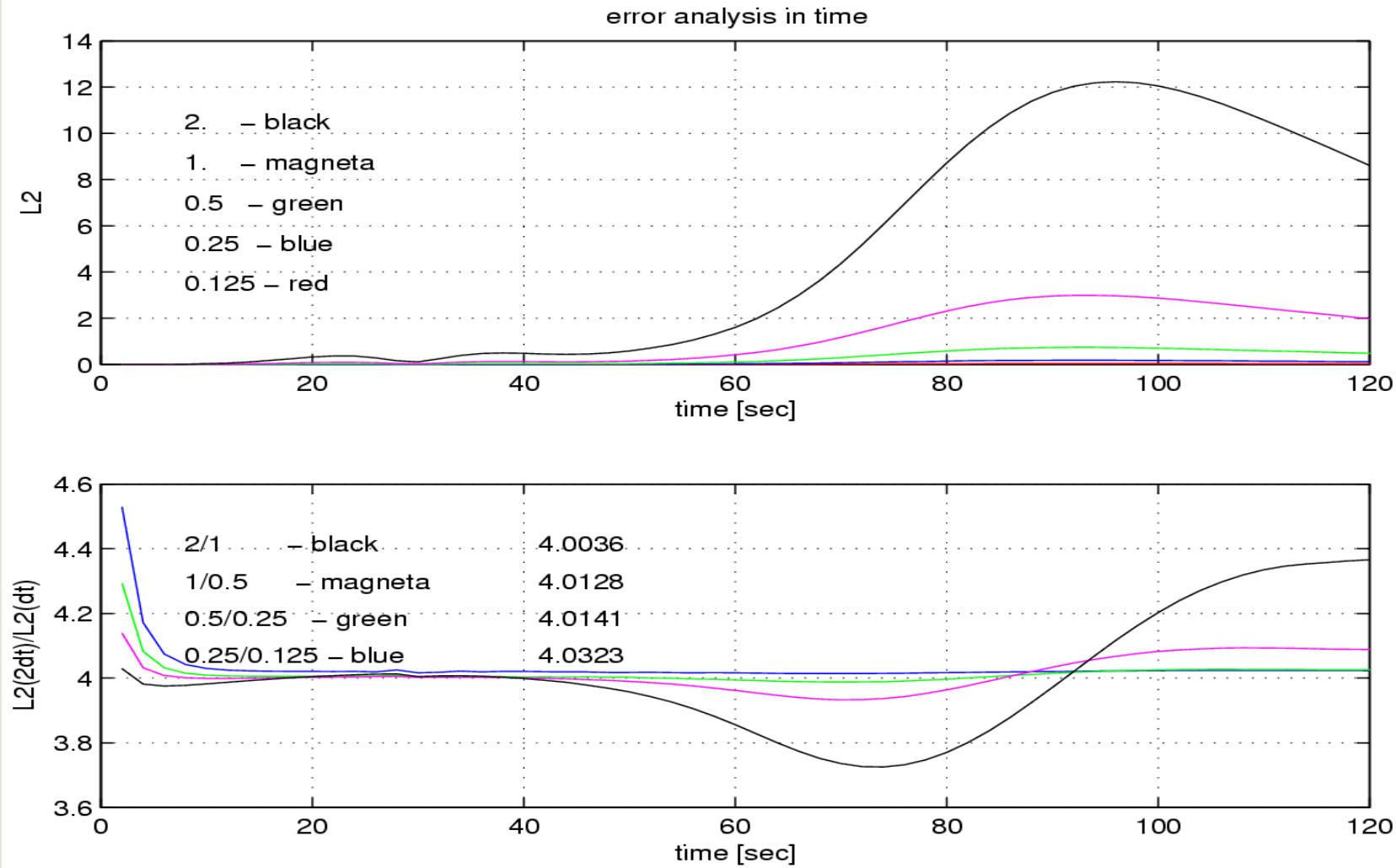
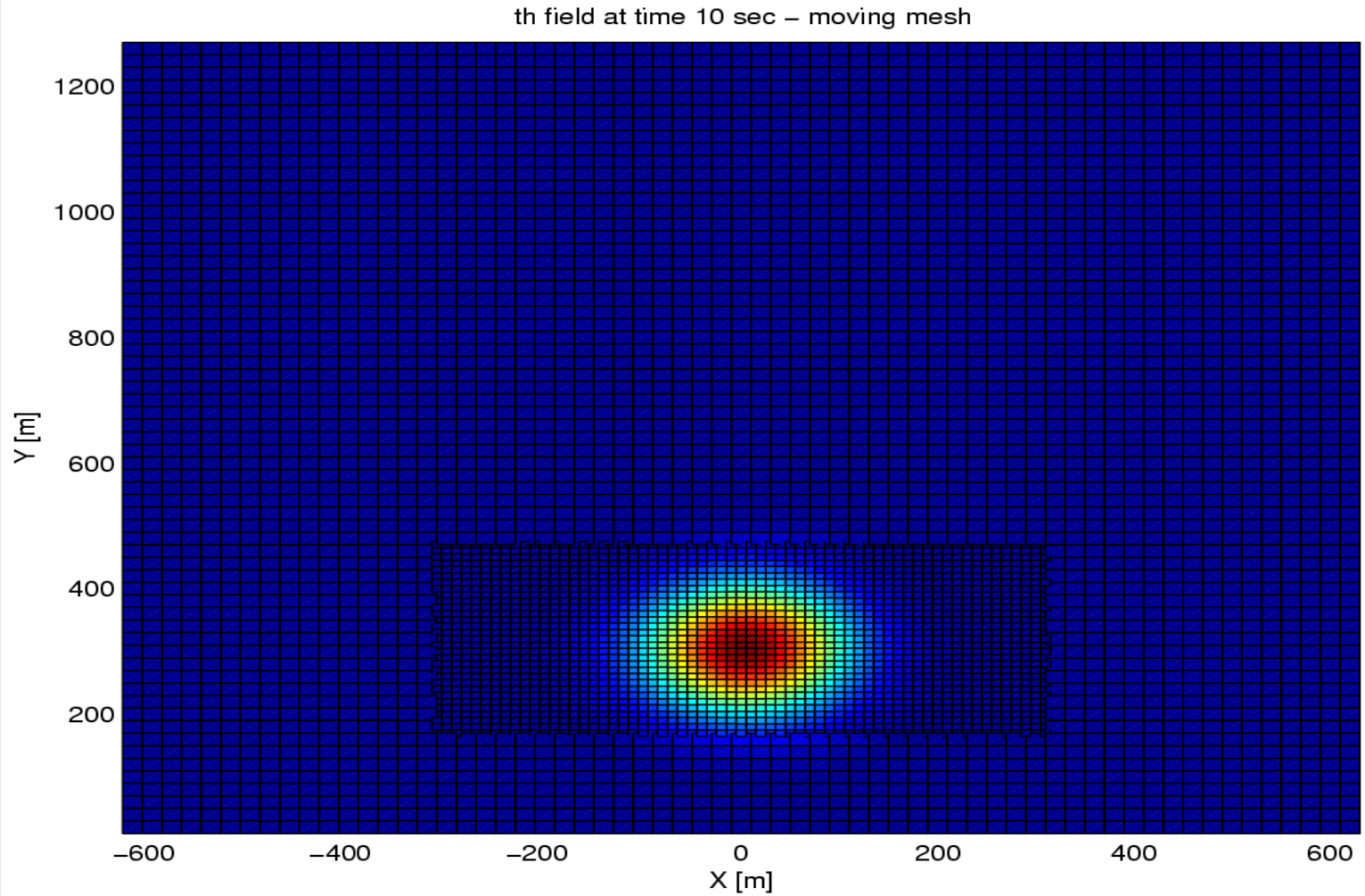
Static Mesh, Error Analysis



Moving Mesh, Potential Temperature



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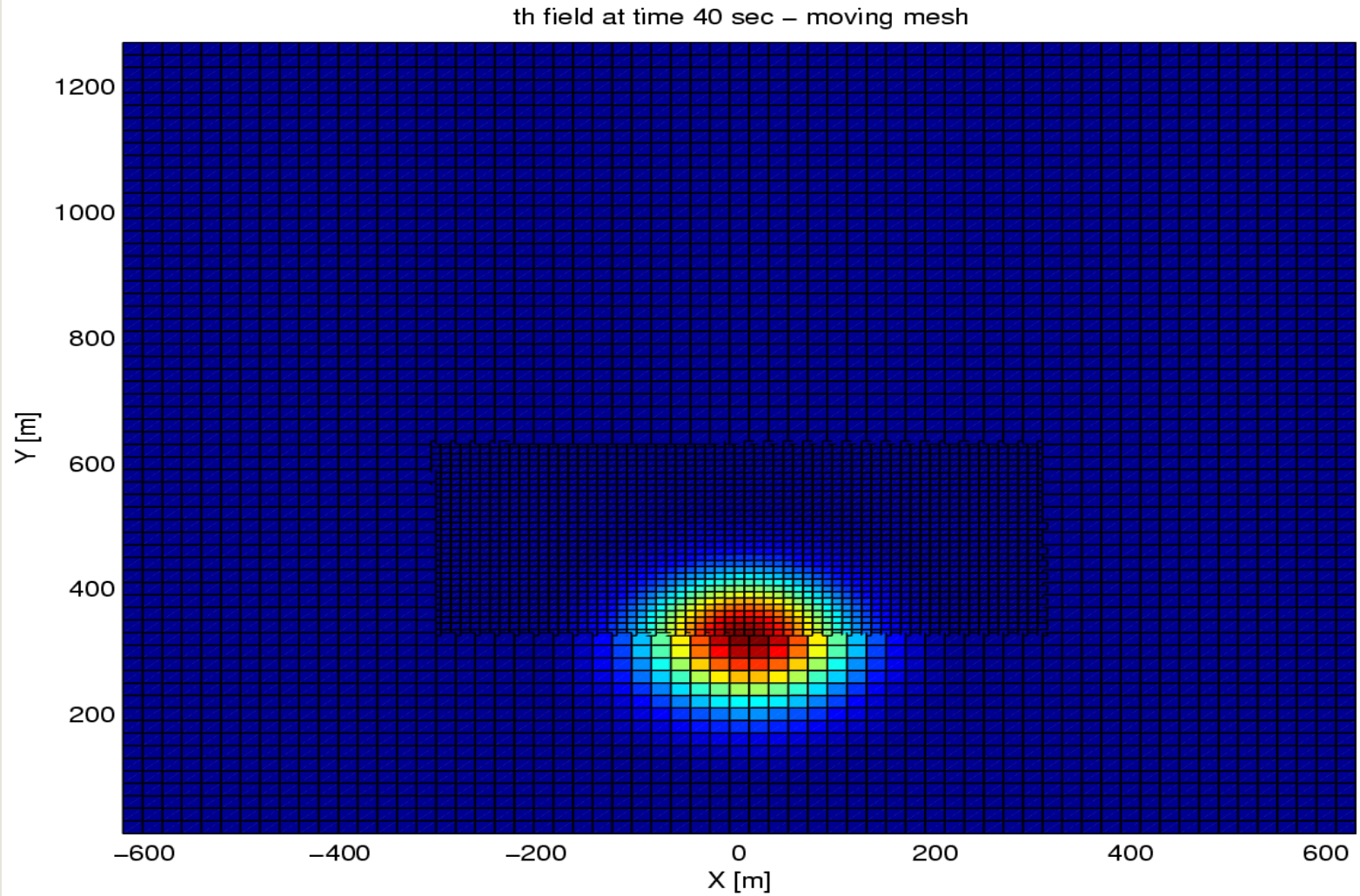
Moving Mesh, Potential Temperature



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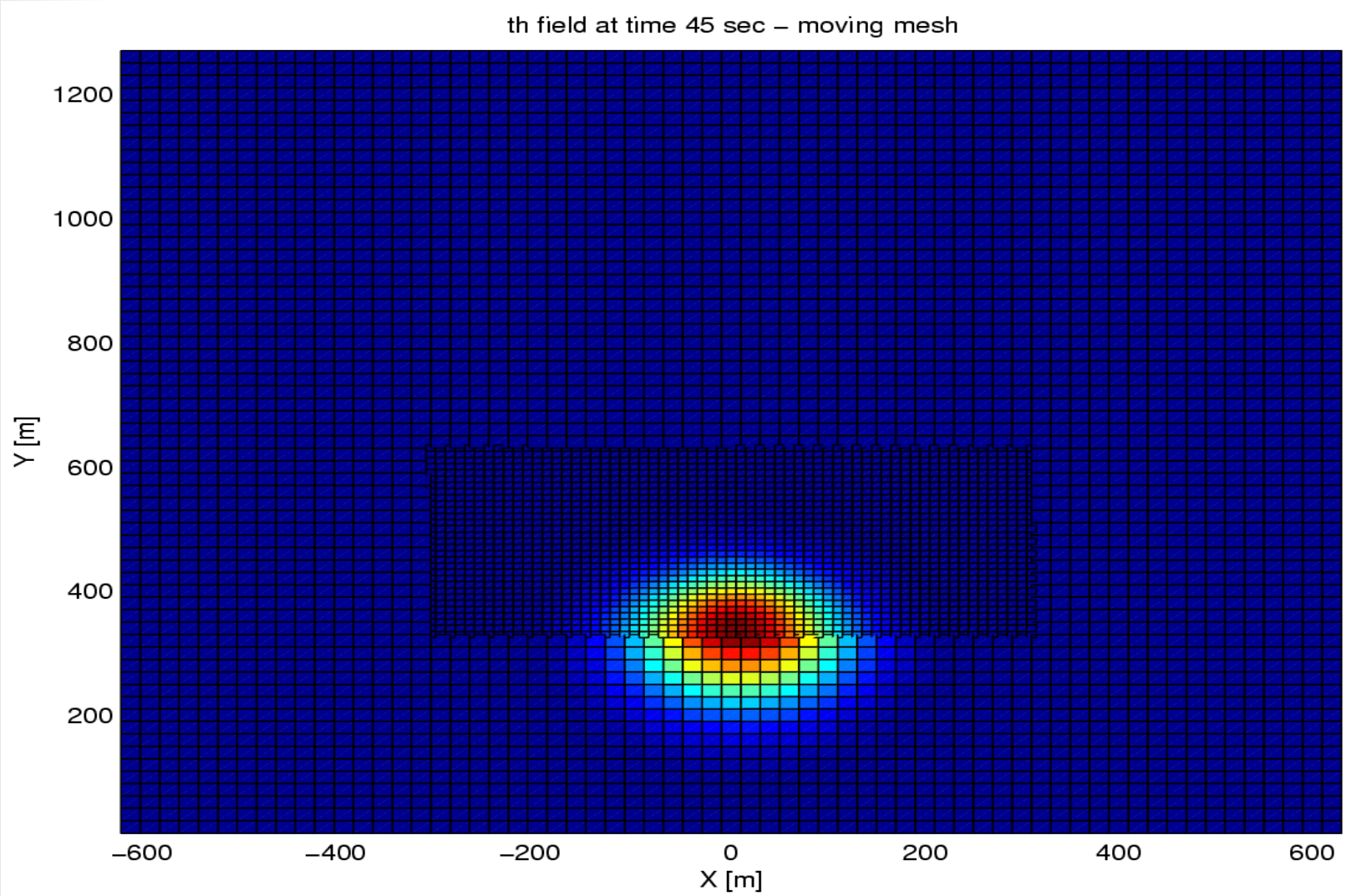

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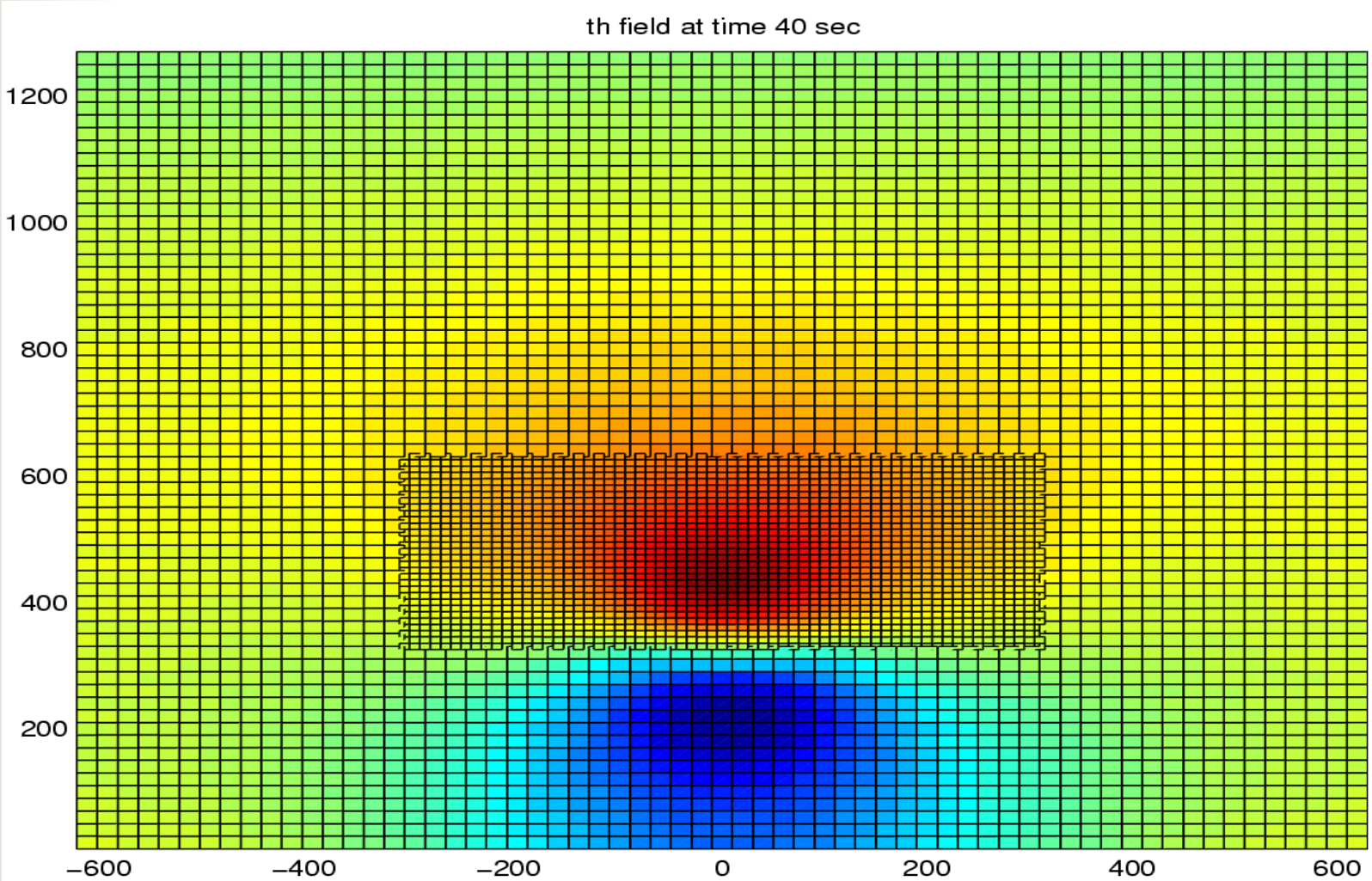

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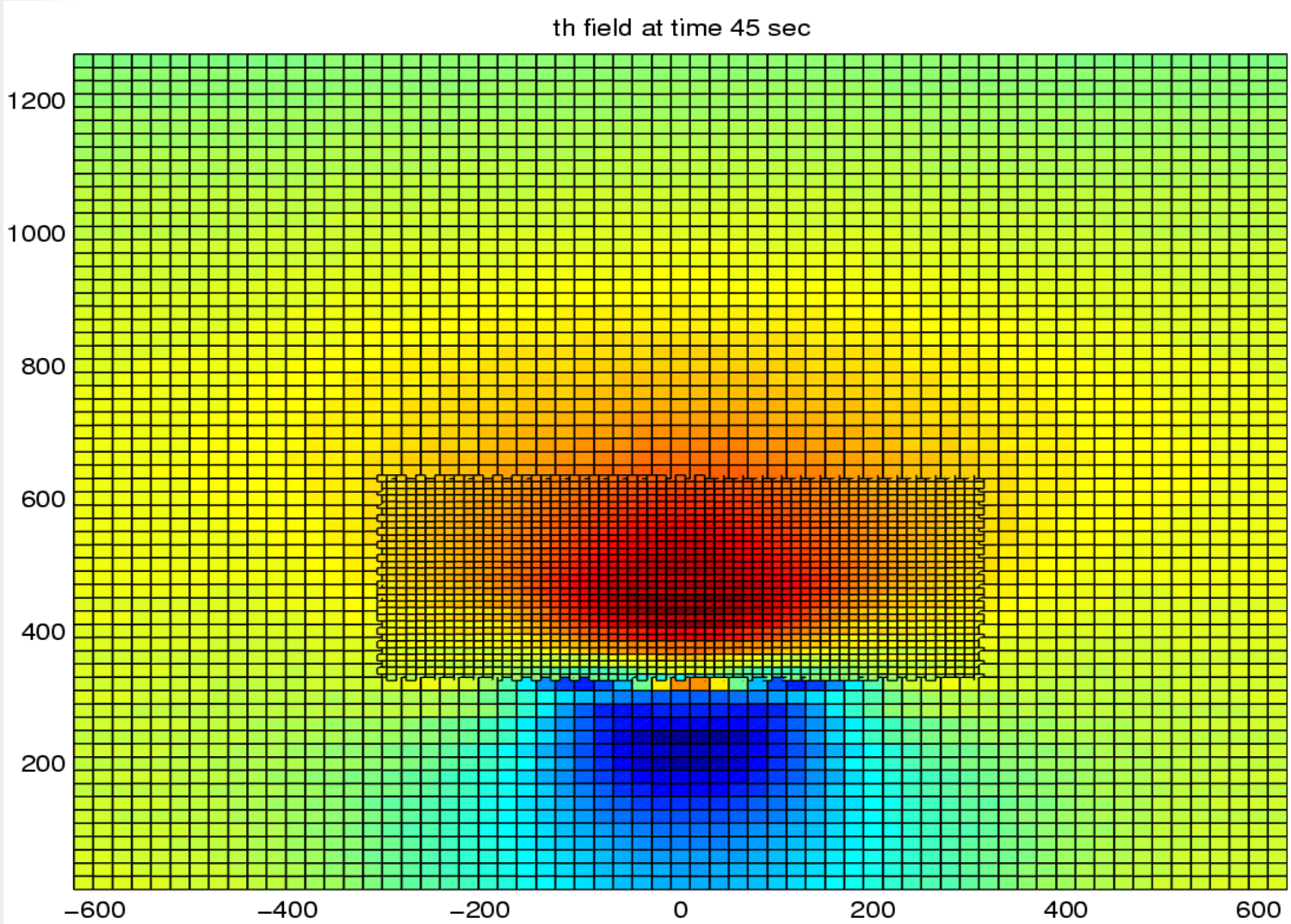

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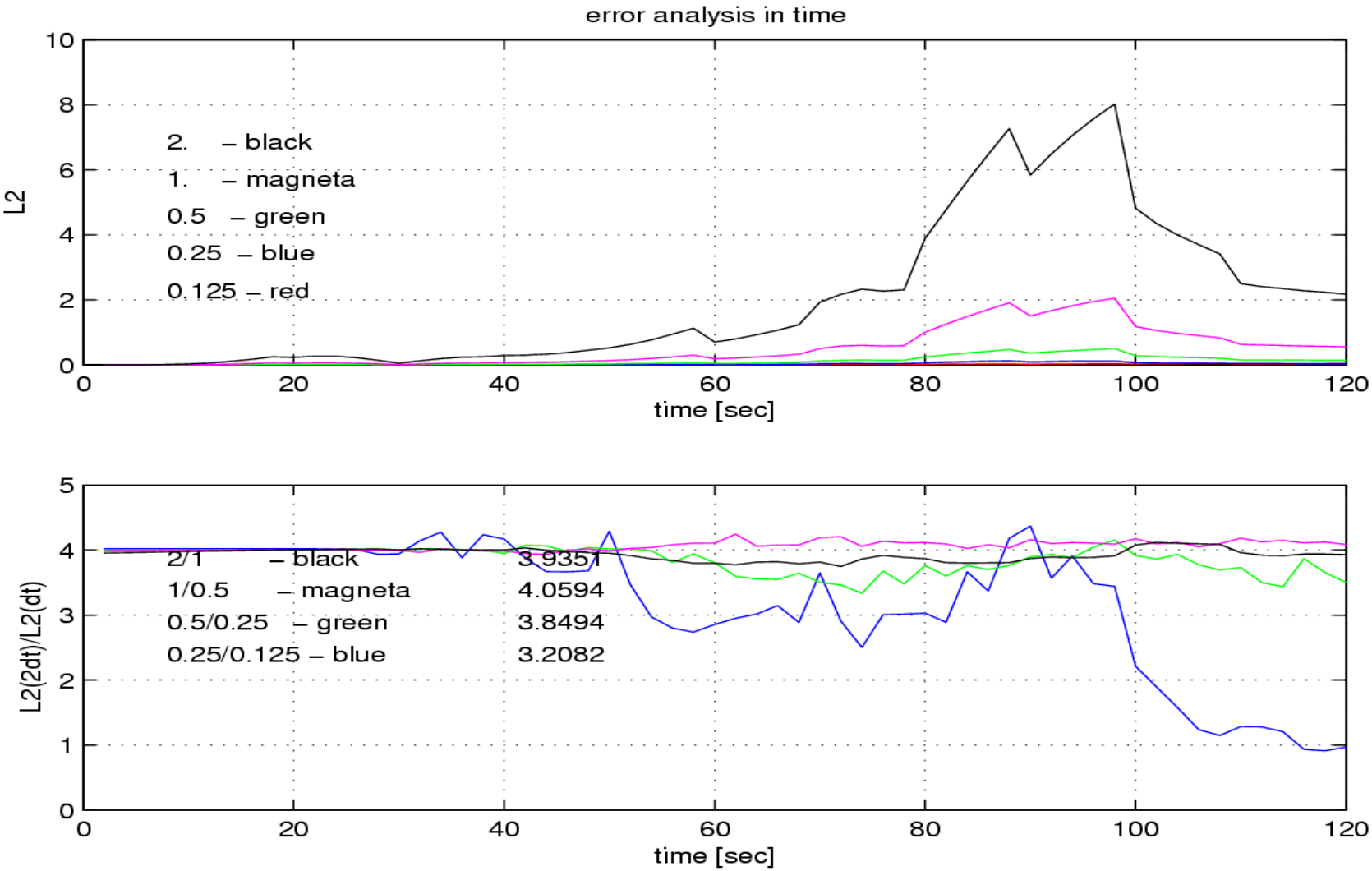

Future Plans

- Extend AMR solver into 3-D. Target applications are as follows:
  - A global code of Mars linked to a sub-surface model (Where's the water?)
  - Wildfires
- Continue to study higher-order time differencing formulations